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In this issue: **ANTI-AIRCRAFT MISSILE GUIDANCE**

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THE COVER

This month's cover symbolizes the basically intellectual nature of all forms of guidance, though dealing here specifically with anti-aircraft missiles.

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IN SERVING Raytheon's technical personnel one intent of Electronic Progress, as stated in its initial editorial, has always been to emphasize ". . . broader information which will inform and generate thought." Acting in the spirit of that policy, we are presenting this somewhat experimental issue. For the first time technical articles do not predominate, yet we believe that all the material presented here is of interest to and has significance for the technical people in the Company.

Essentially, this issue reflects the interest of Raytheon engineers in the diverse factors which relate to their work. Broadly, these factors include the engineer's interest in seeing the over-all concept and the underlying reasons for the projects to which he is assigned; his interest in his own future; the possible influence to be had on his work by new scientific discoveries; and the question of where his own contributions fit into the total scheme. In this issue, one of Raytheon's management training activities is described; Value Engineering, a new approach to an old problem, is discussed; and as a new venture, one scientist's views on a major policy issue in electronics, the planning of weapons systems, are presented.

This, then, is the experiment. We hope it meets with your approval.

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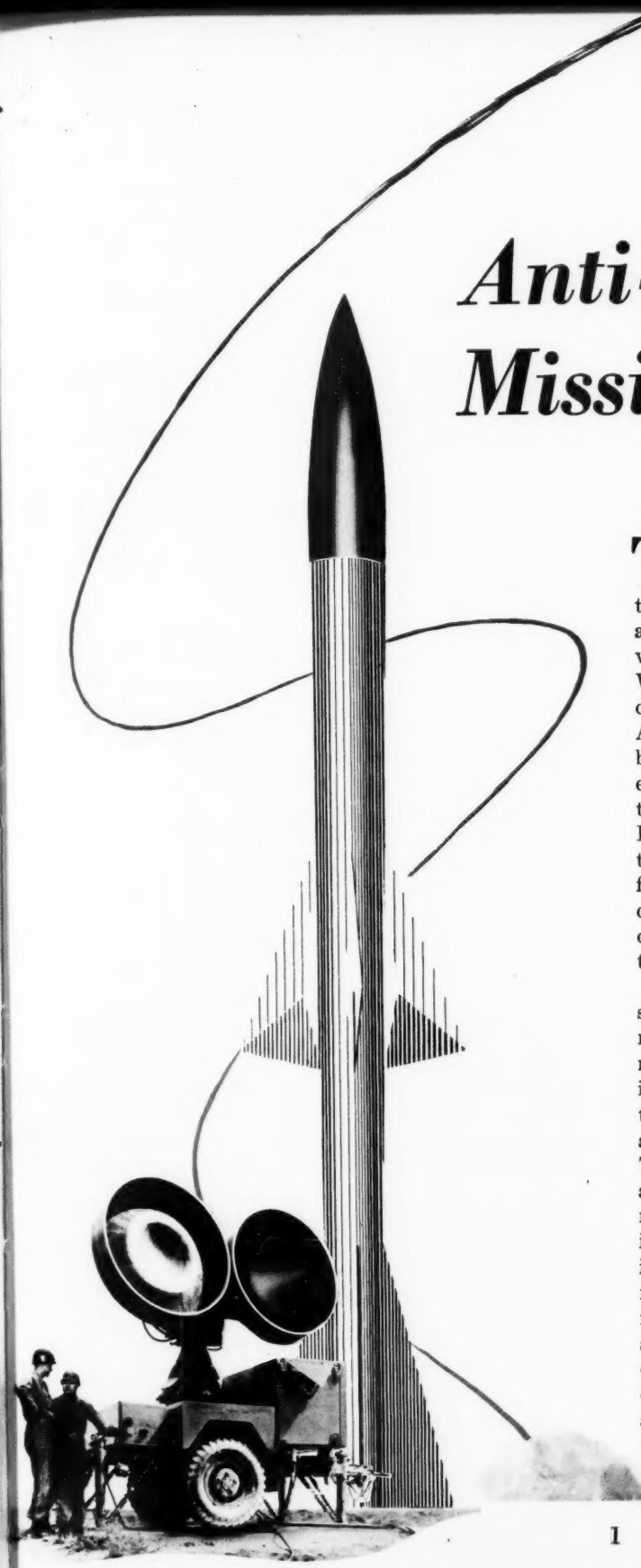


Anti-Aircraft Missile Guidance

T. L. Phillips

Bedford Laboratory

The anti-aircraft guided missile is today man's most technologically advanced means of defending himself against destruction by air attack. It is a natural advancement from fire-control weapons used during World War II against aircraft of lower speeds and less destruction-dealing capacity than present-day aircraft. At that time, if an attrition of 10 to 20 percent could be inflicted on an attacking bomber force, it became extremely unprofitable for the attacker to return and the anti-aircraft defense was considered effective. However, the advent of nuclear weapons has increased the destruction-dealing capacity of a single bomber by factors of thousands. Consequently, the anti-aircraft defense must approach 100 percent effectiveness to be of any real value. Our greatest potential for reaching this level of effectiveness rests in the guided missile.

Anti-aircraft missiles may be either air-launched or surface-launched with each type having an important mission to fulfill in the organized air defense. Air-to-air missiles form the basic armament of the missile-carrying interceptor. This integrated weapon system has the mission of intercepting enemy bombers as far away as possible from our borders or task forces at sea. The mission is one of defending an entire area and is accordingly termed "area defense". Surface-to-air missiles have the mission of protecting key cities, industrial areas, and individual ships at sea by destroying the bomber before it can attack its target. The mission is one of defending key points on the map and is accordingly termed "point defense". Long range surface-to-air missiles may also be employed for area defense. An area defense weapon may be likened to a defenseman in a hockey game who challenges the attacker any time he makes a threatening gesture, while a point defense weapon is likened to the goalie who must make the final save if he is to thwart the attacker's score. Both types are necessary in the

Figure 1.

integrated air defense.

There are many necessary functions which must be carried out successfully to permit a lethal interception of the target by a guided missile. These include detecting the target, launching the missile, the successful operation of the propulsion, guidance and control systems during the flight, and the fuzing and detonation of the warhead at intercept. In this paper we will limit our interest to the guidance of the missile towards the target.

The function of guidance in rocket-propelled weapons is to continuously sense errors in the missile-to-target intercept geometry and to continuously translate these errors into corrective maneuvers until the interception is accomplished. In brief, guidance provides a high degree of accuracy by substituting automatic closed-loop control for the open-loop calculation and prediction employed in conventional artillery control.

The sensing element in most guidance systems is radar. There are three basic methods of employing radar to guide anti-aircraft missiles. These are command guidance, beam riding, and homing, shown schematically in Figure 1.

In the command system, the missile itself does not perceive the target. Target tracking is done by an external radar, usually located near the launcher. A second radar tracks the missile. Positional information from both is fed to a computer which computes the missile trajectory required for intercept and develops appropriate commands. These commands are continuously transmitted to the missile by a communication link until the interception is completed.

In the beam rider system, the target is again tracked by an external radar located near the launching site. The missile does not perceive the target directly, but detects its own position relative to the radar beam tracking the target. Making use of this information, it attempts to keep itself centered in the beam and hence, like the radar beam it rides, pass through the target.

The homing missile is the most intelligent of the three. It perceives the target with its own radar and computes its own control signals. A homing missile which both radiates its own radar energy and receives target reflected echoes is termed an active homing missile. One which homes on a source of energy originating at the target, such as the heat of its engines, is termed a passive homing missile. One which receives echoes reflected from a target which is illuminated by an external source is termed a semi-active homing missile.

The trajectories which anti-aircraft missiles follow are often dictated by the type of guidance system used. For example, the beam rider trajectory is determined by the missile's attempt to stay in the center of the radar beam. The missile measures its displacement error from the center of the beam and maneuvers in a direction to correct the error. A graphical construction is shown in Figure 2. Note that the missile is always on a line between the radar and target and that it must continuously maneuver to remain in that line even when the target is flying a straight-line course. It is also apparent that even on a high flying target, the beam rider must expend a considerable portion of its flight in the denser air at low altitude. Against very fast targets, the missile is subjected to severe corrective maneuvers in the terminal portions of flight.

A command system, by virtue of its additional missile tracking radar, has greater freedom of missile

trajectory and a more economical up-and-over course is possible, as shown in Figure 3. In the homing missile a collision course is characterized by a line-of-sight from missile to target which does not rotate. (See Figure 4.) Any rotation of the line of sight is an indication of errors from a collision course which must be corrected by missile maneuver. One method for correcting these errors is by proportional navigation wherein the missile rate of turn is made proportional to the rate of turn of the line of sight. The constant of proportionality is normally called the navigation ratio.

The homing missile trajectory is largely influenced by the navigation ratio. Figure 5 shows a series of homing missile trajectories for varying values of navigation ratio and a fixed launching error. When the navigation ratio is one, the missile is flying pursuit and requires an ever-increasing maneuver as it approaches the target. As the navigation ratio is increased, the collision course errors are corrected early in flight, reserving the missile's maneuver capability at the end of flight to counter target maneuvers and noise.

As mentioned previously, the sensing element of most anti-aircraft guided missiles is radar. All types of radar are used from the basic pulse and CW systems to the more complex pulse-Doppler and frequency-modulated CW systems. Pulse radar, the most familiar of all, yields an accurate measurement of target range by accurately measuring time of echo travel. In a tracking pulse radar we are interested in tracking the desired target to the discrimination of all others. To accomplish this a gate in the receiver is placed at the target range. It then tracks the desired echo in range discriminating against other echoes at other ranges.

The simplest form of radar is continuous wave, or CW, in which radar energy is continuously radiated toward the target and the target-reflected echo is continuously received at the radar. Energy reflected from a moving target undergoes a frequency shift proportional to the target's radial speed. This is the well known Doppler effect. At the radar a comparison is made between the frequency of the transmitted energy and that reflected from the moving target, yielding a Doppler beat frequency proportional to the target radial speed. Echoes arriving at the radar from targets of different speeds will produce different Doppler frequencies. Again in a tracking radar it is desirable to discriminate against all but the desired target. As might be supposed in this case, it is done by a gate which tracks the target in speed.

The pulse radar basically yields range information, and the CW radar, speed; extensions can be made to both to yield both range and speed. The pulse radar does this by making use of the Doppler principle, in which case it is termed a pulse Doppler radar. The CW radar does it by using frequency, rather than amplitude, modulation of the radar energy, in which case it

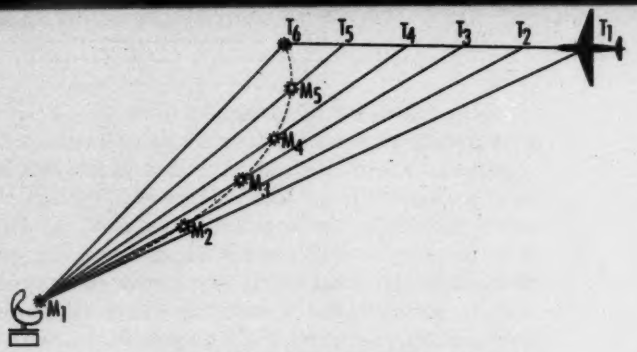


Figure 2. BEAM RIDER TRAJECTORY

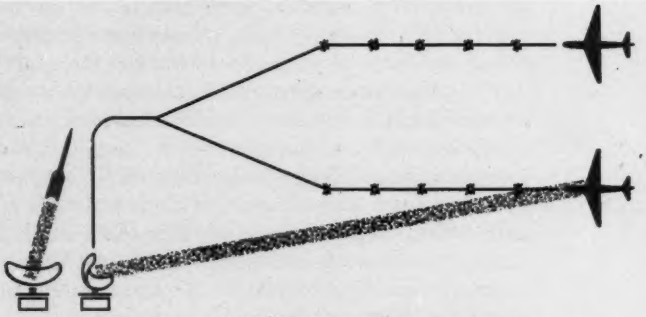
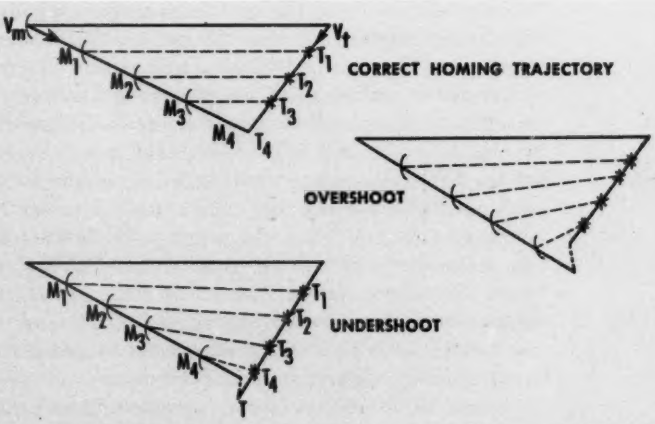
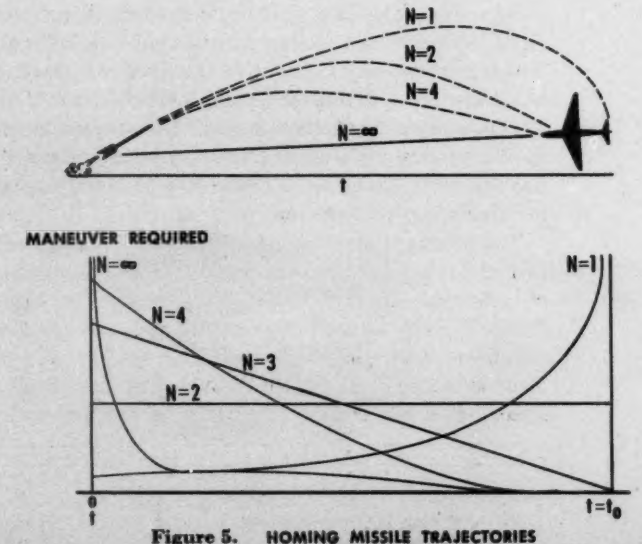


Figure 3. COMMAND SYSTEM TRAJECTORIES



LINE OF SIGHT RATE, MEASUREMENTS MADE IN THE HOMING MISSILE
Figure 4.



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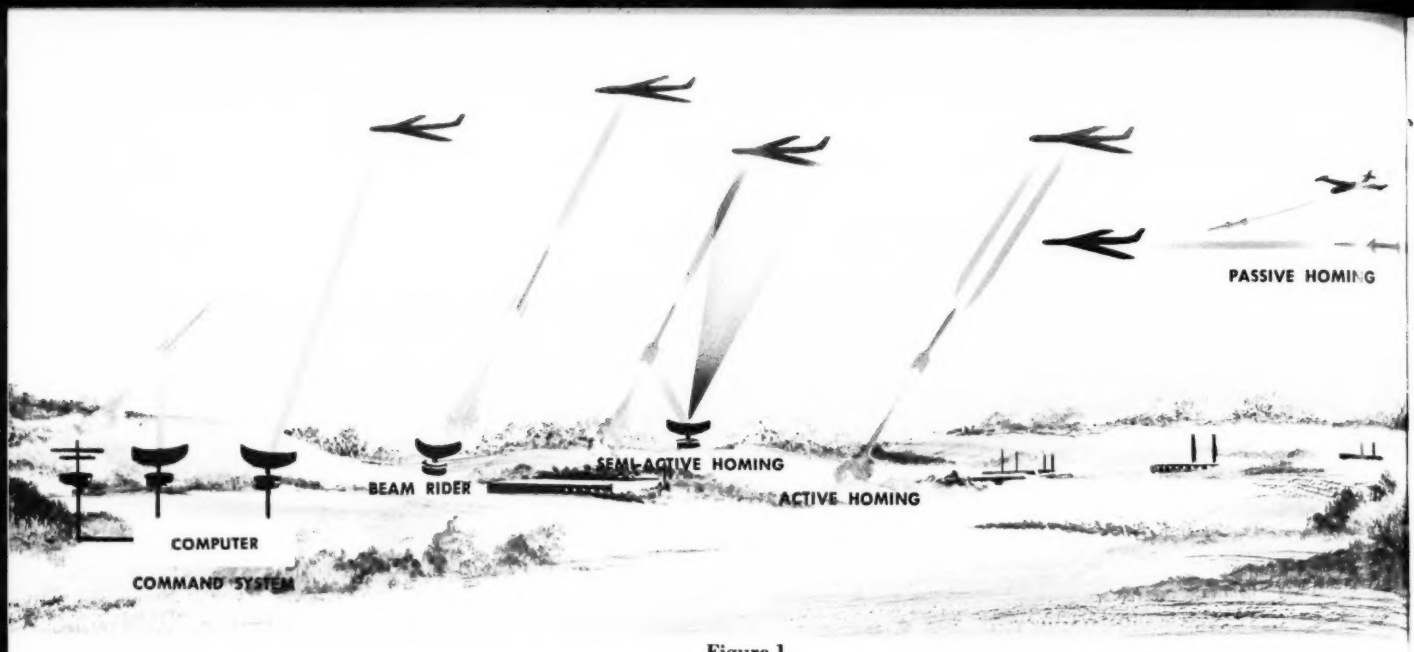

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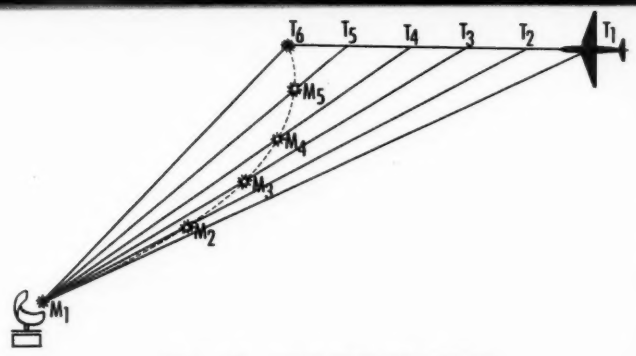
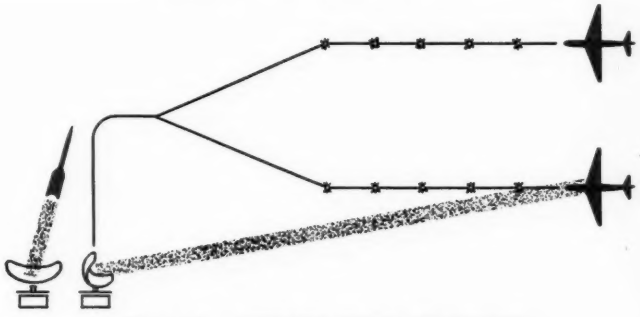


Figure 2. BEAM RIDER TRAJECTORY



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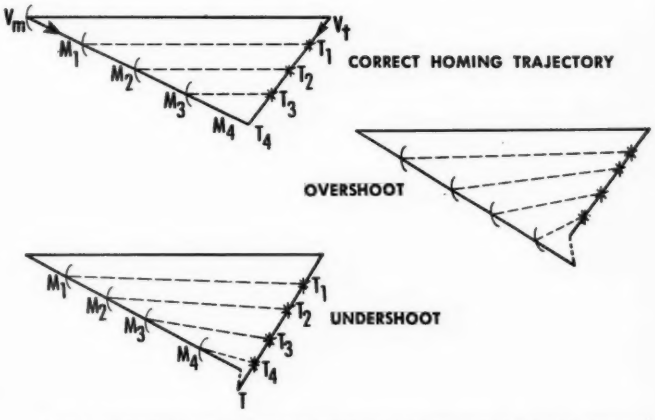

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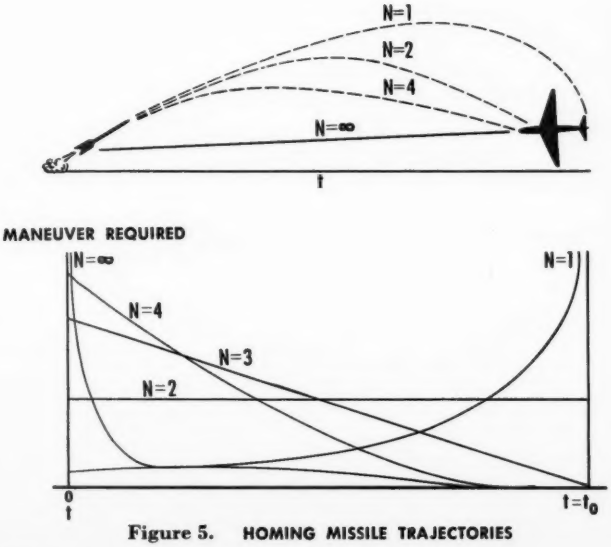


Figure 5. HOMING MISSILE TRAJECTORIES

is termed an FM/CW radar.

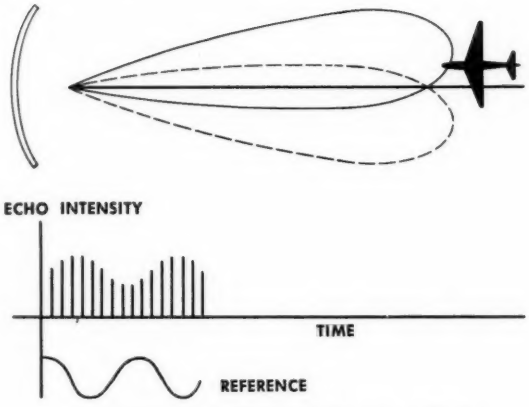
Up until now we have seen how to extract target range and speed information from a radar. But if we are to successfully guide missiles toward the target, we must also know the angular direction of the target. The first step toward accomplishing this is to concentrate the radar energy in a very narrow beam, usually by employing either a focusing lens or a parabolic reflector. The narrowness of the beam or the resolution of the antenna is improved directly as dish diameter is increased or as radar wave length is decreased. To achieve high resolution most guided missile radars are microwave, that is, very short wave length radars.

With energy concentrated in a very narrow beam, it is possible to obtain directional information by moving the beam back and forth across the target to obtain maximum signal strength at the receiver. This would be a very crude measurement of angle since the maximum intensity point of the beam is relatively broad. Higher accuracy can be achieved by off-setting the beam so that it intersects the target at the region of high beam slope and obtaining some type of measurement with either beam motion or beam comparison. This is suggestive of the two most basic methods of obtaining target direction—conical scan and simultaneous lobing, or monopulse.

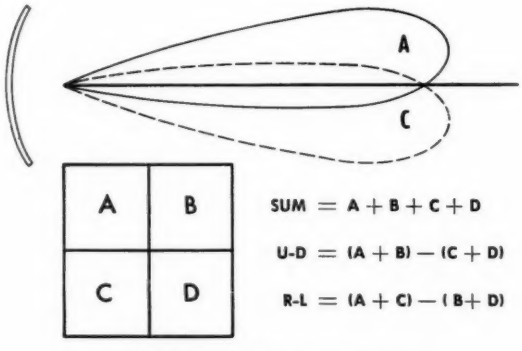
In the conical scan system, the off-set beam is rotated by either an off-set dipole or an off-set reflector, as shown in Figure 6. When the target is in the center of the beam, the echo, whether it be pulsed or CW, will return to the receiver unmodulated (except for Doppler changes). When the target is off the center of the beam, the echo will return modulated at the scan rate. The percentage modulation is a measure of the target error from beam center. The phase of the modulation relative to a scan reference phase is a measure of the polar direction of the error.

In the simultaneous lobing, or monopulse system, the reflector is fed by four separate off-set dipoles to form four orthogonal off-set beams. The energy from these beams is combined at microwave frequencies to yield a sum signal, an up-down difference signal and a right-left difference signal, as illustrated in Figure 7. Thus, a target off boresight in the up-down direction will have more energy in beams A and B than C and D, and will yield an error signal of the proper polarity in the up-down channel. Both conical scanning and simultaneous lobing have been employed with success in missile control systems.

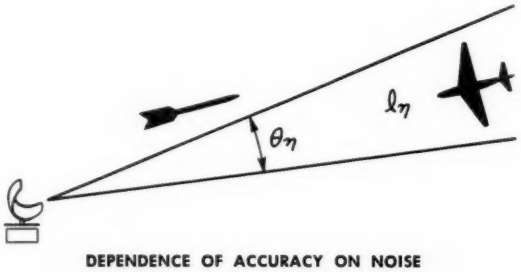
The interception of targets by guided missiles would be highly simplified were it not for the complex nature of practical aircraft targets giving rise to target "noise". Each aircraft is made up of a multitude of significant reflecting areas; the radar receiver sees the composite sum of reflections from each of the reflecting areas. These all tend to beat with one another, giving



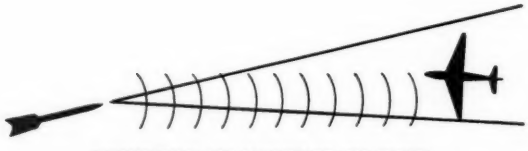
CONICAL SCAN DIRECTION FINDING SYSTEM
Figure 6.



MONOPULSE DIRECTION FINDING SYSTEM
Figure 7.



DEPENDENCE OF ACCURACY ON NOISE
IN COMMAND & BEAM RIDER SYSTEMS



DEPENDENCE OF ACCURACY ON NOISE
IN HOMING SYSTEMS
Figure 8.

rise to a noise-modulated composite echo, a phenomenon which is popularly termed target fading. The tracking radar interprets the composite echo as an RMS, or effective, angle of noise. In addition, each of the reflectors is geometrically separated from all others, giving rise to a wander of the center of gravity of the composite echo. This phenomenon is termed target scintillation and the tracking radar interprets the composite distances between reflectors as an RMS length of noise. While much can be done to reduce target fading by the use of proper direction-finding techniques, scintillation is a property of the particular aircraft only, and the resulting noise is irreducible.

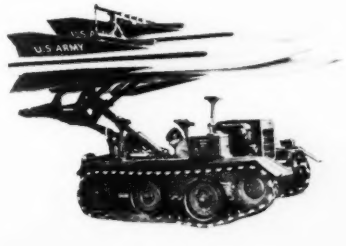
In command and beam-rider guidance, wherein the tracking radar remains on the ground, any fixed angle of noise at the radar becomes an increasing length of noise at the target as the range of the target intercept is increased. (See Figure 8.) The accuracy of these guidance systems is therefore inversely proportional to target range. In the homing system the radar comes in close proximity of the target and the accuracy is independent of range. However, in this system, target scintillation takes on greater significance as the missile comes close to its target. Multiple targets present a problem similar to the scintillation problem created by a single target; that is, separation of reflecting surfaces gives rise to a wander of the center of gravity of the composite echo. When all but the desired target can be discriminated against in either angle, range, or speed, no particular problem exists. However, targets in formation have the troublesome property of appearing at the same angle, range, and speed, at least insofar as the radar's discriminatory capability is concerned. While this situation persists, the radar follows the wandering center of gravity of the formation. As the missile approaches the target, discrimination in angle will occur, at least in the case of the homing missile. The missile must then have enough maneuverability to translate to the resolved target. In addition, targets have the freedom of flying at very high or very low altitudes where missile guidance and control problems become more difficult, or of employing jamming techniques in an attempt to confuse the guidance system.

Very often, it is not so much what the target does but imperfections within the missile which cause large miss distances. Most missiles are controlled by one over-all guidance loop which resolves the missile-to-target geometry. However, to successfully guide the weapon many additional sub-loops are required, wherein servomechanism or feedback principles must be applied. For example, in beam riding we desire to control with a lateral maneuver proportional to the displacement from the center of the beam. (A lateral maneuver is defined here as one which is in any direction except longitudinal; that is, not along the flight axis.) In homing, we desire a lateral maneuver proportional to the target-to-missile line-of-sight rate. In either case the missile's lateral maneuver must be a well defined quantity. At a given flight condition a given deflection of the control surface will give a prescribed lateral maneuver. However, this does not remain the same at a different altitude or speed nor is it necessarily linear with deflection or roll angle. We are saved from this dilemma by actually measuring the missile's lateral maneuver in flight and feeding back this quantity in such a way that the lateral maneuver achieved will faithfully reproduce the corrective lateral maneuver commanded.

The ideal control of an airframe would be one in which only translation to a commanded flight path occurs. However, when a control surface is deflected, the airframe will of necessity also pitch to a new angle of attack. This pitching is usually characterized by poor damping so that the airframe perturbates about the trim angle of attack. Since this perturbation would make the accelerometer loop very unstable, artificial damping is introduced. This is done by measuring the airframe's pitch rate with a gyro and feeding this quantity to the control surface, in a sense to reduce high rates.

A network of loops forms the framework of anti-aircraft missile guidance systems. In addition to the loops which we intentionally introduce into the missile guidance system, there are many parasitic loops which develop from imperfections in the missile guidance components. Among these are g-sensitive control valves and gyroscopes, instruments which are improperly located in a seemingly rigid but actually flexible airframe, imperfectly stabilized antennas, and non-transparent radomes. Analysis and synthesis of such systems would be quite bewildering if each effect were not individually understood. We gain such understanding by considering each effect independently and then linearly superimposing it on the remainder of the system. When three-dimensional or non-linear effects are taken into account, large scale simulators are of assistance. The final proof, however, is in the flight-testing, where many of the unknown factors make their presence felt.

From the brief treatment offered here, it is apparent that the problems of anti-aircraft missile design are many and varied. They are not insurmountable, however, as witnessed by the rapid strides in missile development in recent years.



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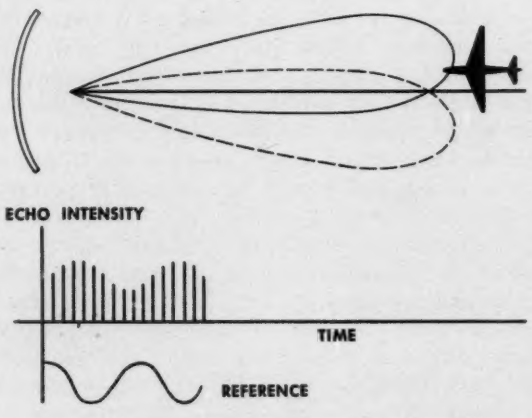
With energy concentrated in a very narrow beam, it is possible to obtain directional information by moving the beam back and forth across the target to obtain maximum signal strength at the receiver. This would be a very crude measurement of angle since the maximum intensity point of the beam is relatively broad. Higher accuracy can be achieved by off-setting the beam so that it intersects the target at the region of high beam slope and obtaining some type of measurement with either beam motion or beam comparison. This is suggestive of the two most basic methods of obtaining target direction—conical scan and simultaneous lobing, or monopulse.

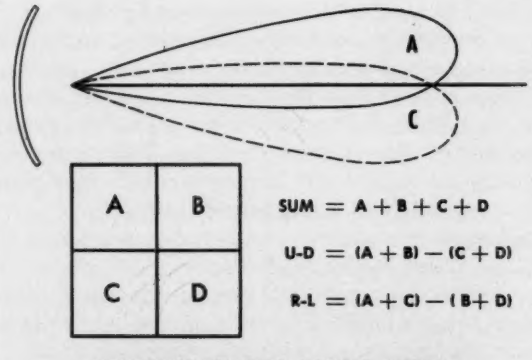
In the conical scan system, the off-set beam is rotated by either an off-set dipole or an off-set reflector, as shown in Figure 6. When the target is in the center of the beam, the echo, whether it be pulsed or CW, will return to the receiver unmodulated (except for Doppler changes). When the target is off the center of the beam, the echo will return modulated at the scan rate. The percentage modulation is a measure of the target error from beam center. The phase of the modulation relative to a scan reference phase is a measure of the polar direction of the error.

In the simultaneous lobing, or monopulse system, the reflector is fed by four separate off-set dipoles to form four orthogonal off-set beams. The energy from these beams is combined at microwave frequencies to yield a sum signal, an up-down difference signal and a right-left difference signal, as illustrated in Figure 7. Thus, a target off boresight in the up-down direction will have more energy in beams A and B than C and D, and will yield an error signal of the proper polarity in the up-down channel. Both conical scanning and simultaneous lobing have been employed with success in missile control systems.

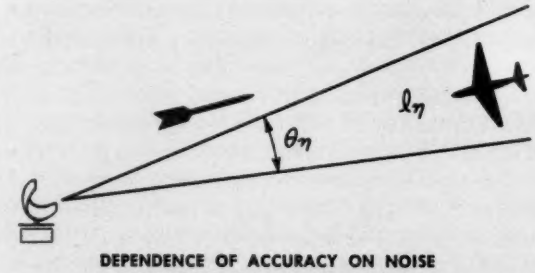
The interception of targets by guided missiles would be highly simplified were it not for the complex nature of practical aircraft targets giving rise to target "noise". Each aircraft is made up of a multitude of significant reflecting areas; the radar receiver sees the composite sum of reflections from each of the reflecting areas. These all tend to beat with one another, giving



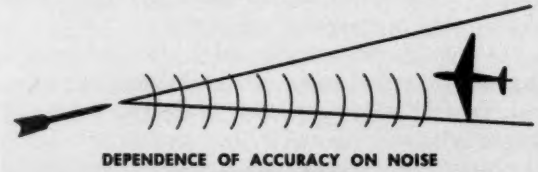
CONICAL SCAN DIRECTION FINDING SYSTEM
Figure 6.



MONOPULSE DIRECTION FINDING SYSTEM
Figure 7.



DEPENDENCE OF ACCURACY ON NOISE
IN COMMAND & BEAM RIDER SYSTEMS



DEPENDENCE OF ACCURACY ON NOISE
IN HOMING SYSTEMS
Figure 8.

rise to a noise-modulated composite echo, a phenomenon which is popularly termed target fading. The tracking radar interprets the composite echo as an RMS, or effective, angle of noise. In addition, each of the reflectors is geometrically separated from all others, giving rise to a wander of the center of gravity of the composite echo. This phenomenon is termed target scintillation and the tracking radar interprets the composite distances between reflectors as an RMS length of noise. While much can be done to reduce target fading by the use of proper direction-finding techniques, scintillation is a property of the particular aircraft only, and the resulting noise is irreducible.

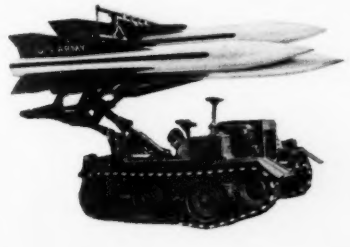
In command and beam-rider guidance, wherein the tracking radar remains on the ground, any fixed angle of noise at the radar becomes an increasing length of noise at the target as the range of the target intercept is increased. (See Figure 8.) The accuracy of these guidance systems is therefore inversely proportional to target range. In the homing system the radar comes in close proximity of the target and the accuracy is independent of range. However, in this system, target scintillation takes on greater significance as the missile comes close to its target. Multiple targets present a problem similar to the scintillation problem created by a single target; that is, separation of reflecting surfaces gives rise to a wander of the center of gravity of the composite echo. When all but the desired target can be discriminated against in either angle, range, or speed, no particular problem exists. However, targets in formation have the troublesome property of appearing at the same angle, range, and speed, at least insofar as the radar's discriminatory capability is concerned. While this situation persists, the radar follows the wandering center of gravity of the formation. As the missile approaches the target, discrimination in angle will occur, at least in the case of the homing missile. The missile must then have enough maneuverability to translate to the resolved target. In addition, targets have the freedom of flying at very high or very low altitudes where missile guidance and control problems become more difficult, or of employing jamming techniques in an attempt to confuse the guidance system.

Very often, it is not so much what the target does but imperfections within the missile which cause large miss distances. Most missiles are controlled by one over-all guidance loop which resolves the missile-to-target geometry. However, to successfully guide the weapon many additional sub-loops are required, wherein servomechanism or feedback principles must be applied. For example, in beam riding we desire to control with a lateral maneuver proportional to the displacement from the center of the beam. (A lateral maneuver is defined here as one which is in any direction except longitudinal; that is, not along the flight axis.) In homing, we desire a lateral maneuver proportional to the target-to-missile line-of-sight rate. In either case the missile's lateral maneuver must be a well defined quantity. At a given flight condition a given deflection of the control surface will give a prescribed lateral maneuver. However, this does not remain the same at a different altitude or speed nor is it necessarily linear with deflection or roll angle. We are saved from this dilemma by actually measuring the missile's lateral maneuver in flight and feeding back this quantity in such a way that the lateral maneuver achieved will faithfully reproduce the corrective lateral maneuver commanded.

The ideal control of an airframe would be one in which only translation to a commanded flight path occurs. However, when a control surface is deflected, the airframe will of necessity also pitch to a new angle of attack. This pitching is usually characterized by poor damping so that the airframe perturbates about the trim angle of attack. Since this perturbation would make the accelerometer loop very unstable, artificial damping is introduced. This is done by measuring the airframe's pitch rate with a gyro and feeding this quantity to the control surface, in a sense to reduce high rates.

A network of loops forms the framework of anti-aircraft missile guidance systems. In addition to the loops which we intentionally introduce into the missile guidance system, there are many parasitic loops which develop from imperfections in the missile guidance components. Among these are g-sensitive control valves and gyroscopes, instruments which are improperly located in a seemingly rigid but actually flexible airframe, imperfectly stabilized antennas, and non-transparent radomes. Analysis and synthesis of such systems would be quite bewildering if each effect were not individually understood. We gain such understanding by considering each effect independently and then linearly superimposing it on the remainder of the system. When three-dimensional or non-linear effects are taken into account, large scale simulators are of assistance. The final proof, however, is in the flight-testing, where many of the unknown factors make their presence felt.

From the brief treatment offered here, it is apparent that the problems of anti-aircraft missile design are many and varied. They are not insurmountable, however, as witnessed by the rapid strides in missile development in recent years.



Management

R. Story

Training Center,
Personnel Relations

One of the most interesting phenomena to emerge on the American business scene since World War II has been the management development program. A review of the literature of the training field prior to the war shows little that could pass under the label of management development. Indeed, most industrial training activities prior to 1945 were concerned almost wholly with the development of manual skills. About the nearest thing to management development as we know it today were programs beamed at first and second line supervision and carrying the designation "Foreman Training." For the most part these programs were concerned with imparting the "know how" aspects of the supervisor's job (planning, scheduling, processing, methods, training personnel and the like), with not too much attention given the broader aspects of management function. This is not to say that these programs were not adequate for their purpose and time. One of the most critical elements confronting management today (that of motivating people to the accomplishment of a common goal) was built into a depression labor force. The supervisor was not so much concerned with the broad aspects of human relations, industrial psychology, knowledge of labor law and other attributes which are today the standard vocabulary of management.

A few of the factors which have combined to point up the need for greater management sophistication are: sixteen years of full, or almost full employment, the enormous growth in the size and complexity of the industrial establishment, industry's increasing awareness of its social responsibilities, and the four year period of war which prevented the gaining of industrial experience essential to the manager. Out of this need have grown today's management development programs. At present, there is scarcely a university of national repute which does not offer some sort of program directed at the problem of developing managers for industry. Locally, the Advanced Management Program of Harvard and the Sloan Fellowship Program at M.I.T. are outstanding examples of education's response to the need. Simultaneous with the academic program, individual companies have been moving forward with their own programs, so that today, the large industrial firm which does not have some form of management training is definitely in the minority.

All this may appear to be a very round-about way of getting at the problem of developing the engineer in management. However, the goal of management development for the engineer is precisely the same as that for any other professional group. The goal of our own management training program at Raytheon is first to provide increased opportunities to improve ability in present assignments and to prepare participants for positions of increased responsibilities. These objectives fit the accountant, the lawyer, and the personnel man, equally as well as they do the engineer. The problem with the engineer arises from the generally accepted concept that engineers are less sensitive to the social and human relations values upon which so much attention has been focused. (Whether this is true or not is a matter of speculation which might be more appropriately discussed elsewhere.)

It is true that the engineer is a specialized individual, who has been required to give more attention to those things which can be measured and to shy away from those things which cannot be. Practically by definition, the engineer is a person who enjoys working with problems which are subject to a logical and reasoned solution. More often than not, however, the problems involved in human relationships have very emotional origins and, therefore, a solution which seems to work well in one instance may simply aggravate the problem in the next. Small wonder that the engineer, accustomed to getting the same results each time he exactly duplicates an experiment, is frustrated. His best engineering techniques do not seem to work when human beings are involved.

Management Training Course in session at the Training Center.

Training

How, then, is this condition to be reconciled with the manifestly clear desire of the majority of engineers to move upward in the management group? At a recent conference held in Boston at the request of the President's Commission on the Development of Engineering and Scientific Personnel, one speaker referred to a survey of engineers made by the commission in which 90% of those surveyed indicated management aspirations.

Such aspirations, however, are more simply stated than resolved. One approach might be simply to thrust the engineer into a management situation and let him acquire the art by osmosis, trial and error or the application of the IOTM method (Inspiration of the Moment). Another approach is to expose the engineer in some systematic way to the body of knowledge which has been accumulated on the art of management. This latter approach is one which is being taken at Raytheon through its Management Development Course which began in March, 1957. Seeking to increase management efficiency and to assure the availability of an adequate number of qualified replacements at all management levels, as well as to provide members of management with greater opportunity to improve present job efficiency and prepare for positions of increased responsibility, the course covers a period of nine months, during which the participants meet for one full day each week.

The course has been designed to cover three broad phases of management, with approximately three months devoted to each phase. The first phase, that of orientation, has been devoted to a broadening of knowledge of the Company, its organization, history, policies and procedures, and other types of information which will increase understanding of the administrative framework within which the manager must function.

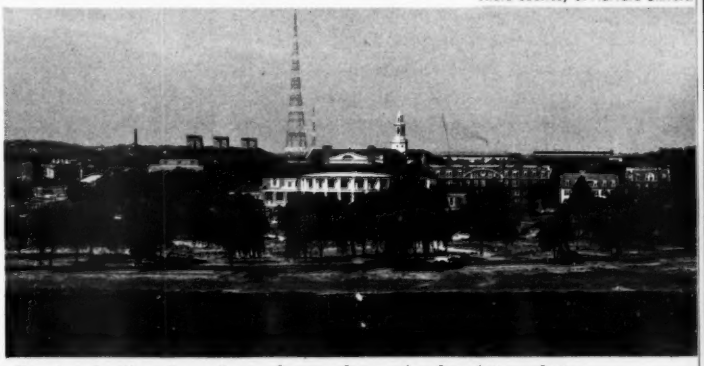
The second phase of the program is devoted to the scientific aspects of management. Included in this phase are full-day sessions on such topics as Industrial Dynamics, The Quantative Approach to Business Problems, Marketing, Finance, Industrial Relations, and Management Problems in Research and Development. Session leaders have been drawn from the faculty of the School of Industrial Management, Massachusetts Institute of Technology.

The third phase of the program, scheduled to begin in February, 1958, will be devoted to the Human Aspects of Management and will provide information on human relations skills and increase understanding of the factors which influence our personal relationships. In this last phase, session leaders will be drawn from the faculty of the Harvard Graduate School of Business.

Inasmuch as this is the first program of its type to be established at Raytheon on a company-wide basis, it is primarily experimental in nature. The initial group includes 14 participants representing all operations of the company, selected by Division or Operations General Managers from middle-management. It is the responsibility of the initial participants to assist in the evolution and refinement of the course to assure its maximum value in future sessions to a diversified group of management personnel.

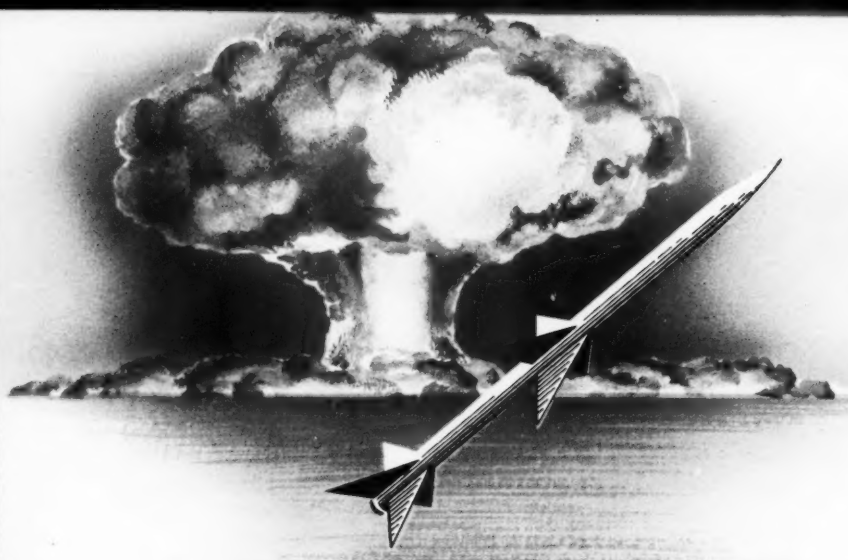
As with all programs of this type, it is difficult to devise a yardstick for measuring its success. The enthusiasm of the participants throughout the course, as well as that of company management personnel who contributed to the first phase of the program, has been unflagging. Since the course was inaugurated, four of the members of the group have been promoted to positions of higher responsibility. The most important consideration, however, lies not in the mechanics of the program nor in the individuals involved, but in the program itself as an expression of the company's interest in the growth and development of its management corps.

Photo courtesy of Harvard Universi



Session leaders have been drawn from the faculties of the Harvard Graduate School of Business and the School of Industrial Management, Massachusetts Institute of Technology.

Photo courtesy of M.I.T.



WEAPON SYSTEMS PLANNING

M. W. Arsove
Wayland Laboratory

More than a decade has passed since the end of World War II, yet we find ourselves in a state of international tension and great military activity at home which is unique in the "peacetime" history of the United States. Military and Industry have found it essential to unite in the expenditure of huge sums of money and time on weapon system programs for defense preparedness. In some cases, this has resulted in a sense of urgency that rivals "crash" programs at the height of the war.

Much of this activity has been prompted by the discovery during the past several decades of certain fundamental scientific principles having a profound bearing on the design of weapon systems. Recent successes in developing new construction materials and in solving complex and difficult engineering problems have also played an important role. As a result of these achievements in pure and applied science, completely new concepts of warfare have been evolved and we find that our arsenal of weapon systems needs to be altered radically.

Atomic weapons, nuclear propulsion, the current variety of long and short range missiles, artificial satellites, all have combined to force radical changes in our concepts of military strategy and tactics. To take one example, nuclear propulsion and advances in hull design have recently given us the true submarine with its unlimited endurance at high speed. When this type of boat is armed with submerged-launched, long range missiles such as Polaris, almost any land target lies under the threat of nuclear attacks. Unlike attacks by ICBM, where the geographic location of the launcher is fixed and known to the enemy, these missiles are launched from disperse and mobile platforms hidden in a medium where detection of the launcher is extremely difficult. The submarine strike system thus combines features of missiles and submarines in one efficient weapon system.

A second example of a new weapons concept results from the combination of atomic warheads with missiles. Although short range missiles were used even during World War II, only with the advent of the high-yield warhead did it make sense to develop missiles with ranges of thousands of miles. All of us are aware of the formidable problems of warhead re-entry, propulsion, guidance, and control, among others, that had to be resolved to make the intercontinental ballistic missile a reality.

Modern weapons such as these are expensive, require the solution of difficult problems, take considerable time to develop and perfect, and make large demands on our limited resources of highly skilled scientists and engineers. In the past, weapon systems were relatively unsophisticated and inexpensive. It was possible for different, loosely-coordinated groups to design the major elements of a complete system (vehicle, guidance, weapons, fire control, etc.) and yet achieve adequate performance from the final assembly. As long as a system is not too complex and the cost of rectifying deficiencies in system performance is not exorbitant, a casual approach to integrated system design can be tolerated. However, the casual approach is indefensible for the far more complicated and expensive weapons needed now and in the years to come.

Careful planning is required to insure to the greatest extent possible that all elements of a weapon system will function in concert. Interactions between components must be predicted in the design stage. One call ill afford to ignore the interactions till strange, wholly unexpected maladies appear in the initial tests of the prototype system. The cost to rectify design deficiencies at this stage of the program is exhorbitant.

The need for careful planning begins, however, much earlier in the process of evolution than at system

design. First, the soundness of the concept should be examined. It is of cardinal importance that proposed weapon concepts be analyzed carefully to determine if they will be contemporary with the strategic and tactical environment expected to exist when the weapon is available.

In view of the great economic burden placed on our country to maintain adequate military preparedness, it is equally essential that the decision to pursue one of several weapon systems proposed for a particular mission be reached in the least expensive way. Decisions based on the results of simulator studies and manhours of brainpower are far cheaper than after-the-fact decisions based on hardware tests. The course of action is clear. Weapon systems should be chosen, insofar as possible, by the results of an analysis of operational effectiveness made prior to design and development programs rather than by comparative tests of prototype equipments.

The importance of analyzing the probable operational effectiveness of a system should not be underestimated. The Operations Evaluation Group organized by Philip M. Morse in World War II demonstrated the value of this approach, particularly by the success of its recommendations for combating U-boats and for increasing the effectiveness of our submarines. The subsequent formation of many other operations analysis groups in the government as well as industry was a direct result of the usefulness of the techniques applied first by OEG.

We discussed earlier the need for preliminary evaluation of proposed weapons. When it comes to the actual evaluation, military and industry have their own contributions to make, and one can readily supplement and/or complement the experience of the other.

The basic ingredients for an appraisal of potential strategic and tactical worth are readily available to the military and, because of their skill, training, and abundant experience in strategy and tactics, the military should generally perform this function. In many instances they have developed special facilities to explore the potential of new systems. For example, the Navy War College has conceived and installed the Electronic Maneuvering Board System which permits two groups to "fight" an engagement under completely realistic battle conditions. The battles do not occur according to a carefully controlled plan. Instead, the battle evolves as a consequence of the actions taken by the opposing forces as they gather intelligence with the equipment aboard their submarines, surface ships, or aircraft. An extremely flexible computer is used to simulate vehicle and weapon characteristics, to calculate damage to each combatant, to score the game, and to keep track of all aspects of the battle for the referees. Results from the EMBS include the effects of human reactions under battle conditions.

Clearly, that particular type of analysis is not an industrial function, although the results are of great importance to industry. Nevertheless, contractors who develop weapon systems or any of their major elements, such as the vehicle or the weapon, must thoroughly understand the tactical mission they are designing for. It is in the best national interest, therefore, that contractors have access to the information they need to support an operations research group. Such a group can provide the guidance that will help avoid costly mistakes. (What is more, it is also in the best corporate interest to support such a group since mistakes sap the corporate life blood—profits.)

Industry in its turn can play a key role in solving a vital problem that some branches of the government have been reluctant to acknowledge. It is an engineering fact that there are often several alternate ways to achieve a desired result. As the complexity of weapon systems increases, so does the number of design alternatives. Now it is also a fact that some of the alternates, while perfectly sound in principle, will be far more difficult and expensive to reduce to practice than others. What is more, the hardware resulting from some alternates will be harder to install, operate, and maintain. Clearly, people thoroughly conversant with manufacturing problems and costs as well as those aware of potential operation and maintenance problems should be consulted early in a program—prior to the preparation of detail specification. Unfortunately, this is not always done. The problem is easily resolved if industry is allowed to contribute to the preliminary design.

If industry is to fulfill its proper role in the defense picture, it must remember that a consideration of

human factors is as essential a part of equipment design for the military customer as it is for the civilian customer. In the field of consumer goods, the manufacturer has ably demonstrated his ability to design products which are easy and simple for the consumer to use. Unfortunately, the engineers trained in consumer goods do not generally have a hand in military products. Due to the large volume of defense business over the last fifteen years, new companies have been formed to produce only military items and long-established industries with a commercial product line have formed autonomous divisions devoted exclusively to the military customer. Since modern weapons involve a high order of technical challenge, there has been a strong tendency for these groups to concentrate on the detailed engineering aspects of weapon systems and, in the process, slight the most salient consideration: the ability of military men to employ the weapon system successfully in the field.

As has been seen, the planning and design of weapon systems is both complex and malleable at the present time. Visionary thinking is urgently needed from those most familiar with the technical possibilities—the scientists and engineers in industry. Imagination, when combined with close cooperation between industry and the military to resolve mutual problems, will help us ultimately find the least expensive method of maintaining the soundest possible military position.

Publications and Papers

S. L. Blum	"Effect of Particle Size on Magnetic Properties of Ferrites"
S. L. Blum	"Microstructure and Properties of Ferrites"
D. L. Bobroff	"Independent Space Variables for Small Signal Electron Beam Analysis"
A. J. Caggiano, J. Caloggero, G. Freedman, P. Kaufman	"Characteristics of an Improved Silicon PNP Audio Low Power Alloyed Transistor"
A. J. Caggiano, J. Caloggero, G. Freedman	"Improved Amplification Factors at High Currents for PNP Silicon Transistors"
D. A. Copson	"Microwave Sublimation of Foods"
D. K. Das, K. Dudley, L. Lesensky, S. R. Steele	"Photocell Measurement of Porosities"
G. A. deMars, H. Statz	"A New Surface Current Multiplication Process"
W. T. Eriksen	"Heat Treatment of Silicon in a Kinetic Vacuum System"
G. Freedman	"High-Power Diffused Base Transistor"
G. Freedman, J. Williams, P. Flaherty, D. Root, D. Spittlehouse, W. Waring, P. Kaufman, P. Whoriskey	"A New Five Watt, Class A, Power Amplifier"
E. Handly, W. P. Crossley	"Subminiature Indicator Tube for Transistorized Computors"
H. A. Haus	"Power Flow Relations in Lossless Nonlinear Media"
P. Keisling	"Transistor PPM Equipment Operates Over Wide Temperature Range"
R. E. Lang	"Control Systems"
A. L. MacDonald, W. J. Heinecke	"The Effects of Heat Treatment on Diffused Silicon Material"
W. B. Mitchell, J. Gillette	"Semiconductor Diode Test Methods"
J. R. Patel	"Dislocation Arrangements in Plastically Bent Silicon Crystals"
G. W. Renner, R. A. Plante, T. F. Hueter	"Power Handling Capability of Ferroelectric Ceramics"
P. A. Rizzi	"Ferrite Modulators"
D. Schiff, S. Ziering	"Half-Range Moment Method for Multi-Group, Two-Dimensional Reactors"
E. Schlomann	"Ferromagnetic Resonance in Polycrystalline Ferrites with Large Anisotropy"
E. Schlomann, J. R. Zeender	"Ferromagnetic Resonance in Polycrystalline Nickel Ferrite Aluminate"
E. Schlomann	"Theory of Double Resonance in Nearly Compensated Ferrimagnetics"
T. A. Weil	"Applying the Amplitron and Stabilotron to MTI Radar Systems"
H. Statz, G. A. deMars	"Inversion Layer Transient Measurement Giving Evidence of Finite Mobility of Charges in Outer Surface States"
W. Waring, D. T. Pitman, S. R. Steele	"Germanium Arsenide as Diffusion Surface Compound"
S. P. Wolsky	"Vacuum Microbalance Experiments with Germanium and Silicon"
S. P. Wolsky	"Argon Bombarded Germanium Surfaces"
P. J. Whoriskey	"Two Chemical Stains for Marking P-N Junctions in Silicon"

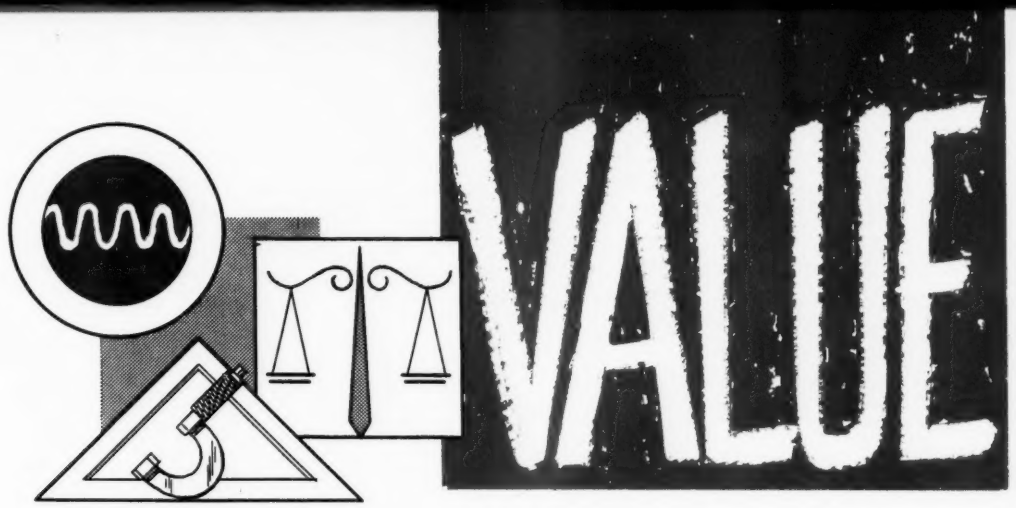
ERRATA ON ERRATA

D. L. McMurtrie, J. P. Ward	"Triggering in Reversible Half-Wave Magnetic Amplifier"
J. R. Patel, S. Lederhandler	"The Behaviour of Oxygen in Deformed Silicon"

Inventions

Congratulations to the following persons for their valuable contributions to Raytheon's portfolio of inventions:

Saul M. Bergmann	High Power Microwave Attenuator
Harry F. Chapell	Crossed-Field Device
Louis Goodman	Stylus
David R. S. McColl	Ferrite Gyrator Modulation
John M. Osepchuk	Interdigital Anode
Roy Paananen & Alan Ede	Backward Wave Oscillator
Roy Paananen & David White	Crossed Field Tube
Ernst Schlomann	Ferromagnetic Microwave Amplifier
Earl J. Shelton	Magnetron Modeloading
Marshall Sirvetz & Joel Zneimer	Magnetic Garnets
Robert V. Smith	Broiler Unit
W. A. Smith, Jr. & George MacMaster	Secondary Emission Vacuum Tube



ENGINEERING

R. G. Munroe J. S. Beebe H. B. Macomber

Wayland Laboratory

Four years ago the Navy's Bureau of Ships faced a multitude of problems associated with rising costs, coupled with the rapid development of new ideas, new forms of raw material, new processes, and new engineering techniques. As a result of their predicament, they began to examine critically the results of an experiment undertaken earlier by General Electric. A new concept of product simplification and improvement had been developed, aimed at substantially reducing costs. The Bureau liked what was found in this program. Here, in a plan called Value Analysis, was an industrial technique that would avail the Navy of more and better equipment for its procurement dollar. The Navy adopted the idea, placing responsibility for its further development with the Bureau of Ships. Soon Value Engineering branches were established in all Naval shipyards, and the results were little short of phenomenal.

"Value," in terms of this program, was declared to be "the lowest price that can be paid at the needed time, in the needed place, for the needed function," and Value Engineering itself is basically a system of techniques and methods for gaining equal or improved functions at minimum cost.

It became apparent that the experience gained in shipyards might be used with equal effectiveness by equipment suppliers. Unfortunately, however, few suppliers grasped the concept of Value Engineering. Those who did were struggling through the pains of organizing to exploit its benefits. Education of employees throughout the organizations was the biggest hurdle to be overcome. In an effort to assist, and to ensure its share of the industry savings potential, the Bureau decided to throw its resources behind a supplier education program. Early in 1957, "Value Engineering of Naval Electronic Equipment," was issued. The scope of this program included:

> ". . . the study and evaluation of the design and manufacture of a particular electronic equipment or system. This includes an intensive and critical review of the operational and maintenance requirements, specifications, design, manufacturing processes, materials, inspections, and testing by the contractor of the equipment to determine the minimum functions and parts, and the least expensive materials, processes, and procedures necessary to produce a functional, maintainable, and reliable equipment. It is intended that the *total cost* of the equipment be reduced without adversely affecting the essential characteristics."

The Bureau also embarked on the preparation of a Value Engineering Handbook, to be made available to suppliers in industry, and to include definitions of terms, case histories, and recommendations for action based on rapidly accumulating experiences.

Shortly thereafter, Captain W. I. Bull, Head of the Electronics Division of BuShips, together with Captain John M. Waters, Director of Value Engineering for BuShips, and Captain Waters' staff, presented the new concept to assembled representatives of all Raytheon Operations. Numerous examples of improved products at reduced costs were displayed. The Bureau's incentive program, designed to encourage suppliers to become proficient at Value Engineering, was outlined.

Suppliers who accepted R & D contracts containing a Value Engineering clause would be paid to perform a Value Engineering function. In the case of a production contract, a percentage of the resulting savings would be retained by the contractor, and the Bureau would still pay for the Value Engineering effort. In preparation for anticipated BuShips business and to establish the nucleus for such a function in terms of other tasks, the Wayland Laboratory established a Value Engineering facility as a part of its Standards Section, and the Government Manufacturing Plant simultaneously established a similar facility.

Personnel, facilities, and records of other firms' experience are now at hand to aid in the establishment of an effective Value Engineering program here, and a sound method of operating within our particular organization is being worked out. As in BuShips, effort at the start is concentrated in limited areas, with in-plant sources of information being developed first. Prime, in this respect, is the need for readily available cost data. People in Engineering, Production, Purchasing, and Accounting, therefore, are all working daily with Value Engineering people to develop a more complete knowledge of the concept, as well as to settle details.

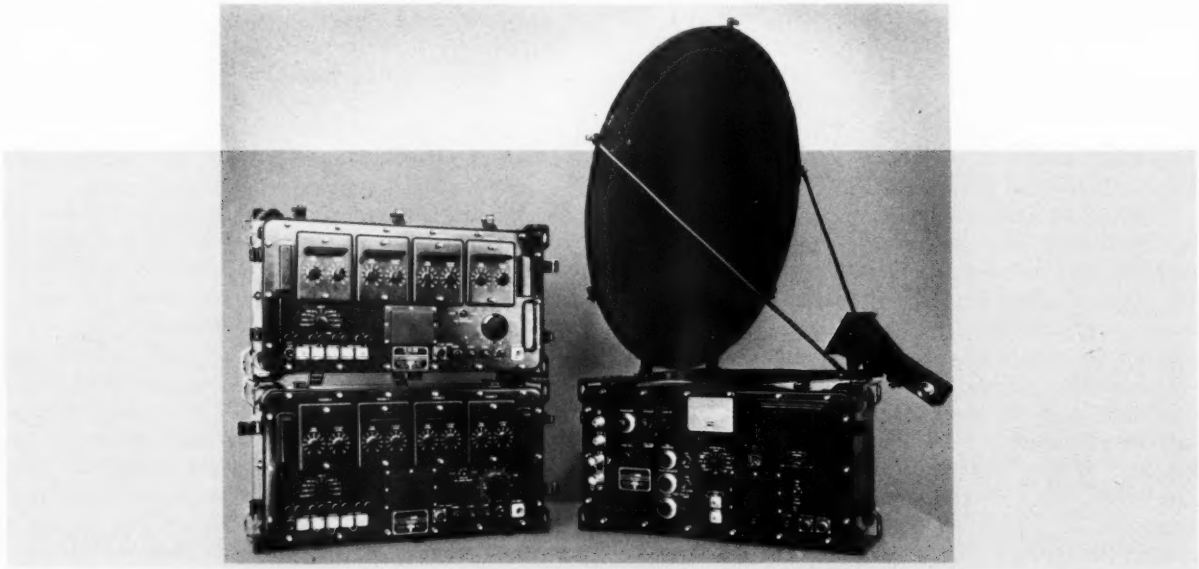
One particular BuShips Value Engineering example occurred in this fashion: A joy stick assembly, used for spot positioning on radar equipment, was priced at $127.00. A 90° motion of the stick was transformed by elaborate gearing to a 270° potentiometer movement. Examining the cost of the detail parts showed the gearing to be the high cost item. Substituting a potentiometer requiring only 90° rotation would eliminate the gearing. Tests showed the performance quality to be the same as before. Savings were $117 per unit. Thousands of these units were procured each year.

There are two elements of interest in this example, aside from the 92% unit savings: (1) the availability of specific cost data which isolated the high cost items; (2) the technique of comparing the cost of a given function with the cost to perform this function in another way. Value Engineering people continuously seek the answers to these basic questions:

(1) What is the part?
(2) What does it do?
(3) What does it cost?
(4) What else would do the job?
(5) What would that cost?

In so doing, they are operating as generalists in product improvement—not as specialists in redesign. Fact gathering, rather than decision making, is their job. With help from the skills of engineering, procurement, production, and specialty vendors, Value Engineering people gather data to be arranged as proposals.

Value Engineering proposals are documented in a uniform way. Each contains a description of the proposed improvement, current cost, cost in time and money to achieve the improvement, and the amount of potential savings as related to scheduled production. The project engineer, evaluating the facts contained in the proposal and the facts available from his special knowledge of the task, approves or rejects it. If approved by Engineering, the proposal goes to Manufacturing. If the production situation in terms of tooling, schedule capability, and stock on hand or on order is compatible with the proposal, it is approved.



The AN/TRC-27, a radio communications relay set, is one of the equipments on which a value engineering study is currently being made.

Manufacturing provides the funds, and a change is executed by Engineering.

As with any other new industrial technique, there are many problems associated with the effective development of Value Engineering within our organization. Among these problems are the inherent human characteristics of resistance to change and resentment of criticism, real or otherwise. Many people will point out that value is held in constant awareness by all and will cite examples that show brilliantly executed savings. Others may express alarm that an unhealthy spirit of competition may spring up between designers and Value Engineering people. And, there is little doubt but what there will be isolated cries that originality is being stifled. Neither sympathetic awareness nor intellectual argument will do the whole job of overcoming this natural resistance. Actual involvement by all concerned is what is needed. As design, purchasing, production, and Value Engineering people work out proposal after proposal, the facts of our improved competitive position will sink home.

Savings, generated by the Value Engineering concept on a full-time day-by-day basis, will not *compete* with savings contributed by our current methods of designing and producing equipment. They will *add* to these savings. Exploration of vendor capabilities and examination and comparison of current designs and manufacturing methods will not stifle design originality. Rather, these processes will create an atmosphere in which originality can flourish, toward greater reliability and better economy of product cost.

The Armed Forces have asked that an objective "second look" be given to the product being produced for their use. Moreover, they have asked that this be done on an organized full-time basis. This puts the concept of Value Engineering beyond the realm of a business nicety. From a competitive viewpoint it is essential. From a corporate viewpoint it is good business.

Instructors Wanted . . .

Raytheon periodically receives inquiries from the local colleges and universities as to the availability of staff members for part-time or evening teaching. If you are interested, please notify James Sterling (Administration Building, Waltham, X-401) who will arrange for contact with the schools.

Calendar

ENGINEERING SEMINARS

Tentative Schedule

Seminars will be held weekly on Wednesdays at 5:20 P.M. at the Wayland Laboratory cafeteria. *Clearance through CONFIDENTIAL will be required* for attendance unless otherwise announced.

"Applications of Coherent Radar"		
D. R. S. McColl, Wayland Lab.	**Mar. 5**	**CONFIDENTIAL**
"What Goes on in the Commercial Department"		
J. H. Beedle, Commercial Equipment Div.	**Mar. 12**	**UNCLASSIFIED**
"Raytheon's Work in the Infrared"		
W. R. Hutchins, Missile Systems Div.	**Mar. 20**	**CONFIDENTIAL**
"Recent Advances in Microwave Tubes and Their Applications"		
W. C. Brown, Microwave and Power Tube	**Mar. 26**	**CONFIDENTIAL**
"Special Tubes, Present and Future"		
R. J. E. Whittier, Industrial Tube Div.	**Apr. 2**	**UNCLASSIFIED**
"Countermeasures and Anticountermeasures"		
H. K. Hudson, Wayland Lab.	**Apr. 9**	**CONFIDENTIAL**

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